Development of Countermeasures to Aid Functional Egress from the Crew Exploration Vehicle Following Long Duration Spaceflight

Completed Technology Project (2009 - 2014)

Project Introduction

Crewmember adapted to the microgravity state may need to egress the vehicle within a few minutes for safety and operational reasons after g-transitions. During exploration class missions the interactions between a debilitated crewmember during re-adaptation to gravity and the prevailing environmental constraints imposed during gravitational transitions may lead to disruption in the ability to perform functional egress tasks. At present, no operational countermeasure has been implemented to mitigate this risk. Therefore, the overall goals of this project are to: 1) investigate performance of motor and visual tasks during simulated perturbation conditions and 2) to develop a countermeasure based on stochastic resonance to enhance sensorimotor capabilities with the aim of facilitating rapid adaptation during gravitational transitions following long-duration spaceflight. Stochastic resonance (SR) is a mechanism whereby noise can assist and hence enhance the response of neural systems by detecting sub-threshold signals. SR thus enables the enhanced detection of relevant sensory signals. SR stimulation using imperceptible noisy vibratory or electrical stimulation has been shown to improve balance function in normal young and elderly subjects, stroke patients, and in the rehabilitation of functional ankle joint instabilities. This project specifically has used imperceptible levels of electrical stimulation of the vestibular system (VSR) as the proposed countermeasure to improve performance in egress tasks. The project has also conducted a series of studies to document human visual performance during simulated low frequency dynamic perturbations and further investigate the efficacy of VSR stimulation on physiological and perceptual responses during otolith-canal conflicts and dynamic perturbations. Goal 1: The objective of two separate studies that were conducted was to document human visual performance during simulated wave motion in the 0.1 to 2.0 Hz range. The main findings of both studies showed that dynamic visual acuity (DVA) is reduced in the vertical plane at frequencies of 2 Hz and in the horizontal plane at frequencies of 0.8 Hz. DVA varies with target location, with acuity optimized for targets in the plane of motion. Thus, low frequency perturbations in horizontal and vertical planes can cause decrements in visual performance that may be exacerbated after long-duration spaceflight. Goal 2: For determining efficacy of VSR stimulation on physiological and perceptual responses during otolith-canal conflicts and dynamic perturbations we have conducted the following series of studies: 1. We have shown that imperceptible binaural bipolar electrical stimulation of the vestibular system across the mastoids enhances balance performance in the mediolateral plane while standing on an unstable surface. We have followed up on the results of this previous study showing VSR stimulation improved balance performance in both mediolateral and anteroposterior planes while stimulating in the mediolateral axis only. 2. We have shown the efficacy of VSR stimulations on enhancing physiological and perceptual responses of whole-body orientation during low frequency perturbations (0.1 Hz) on the ocular motor system using a variable radius centrifuge (VRC) on both physiological (using eye movements) and perceptual

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responses (using a joystick) to track imposed oscillations. The variable radius centrifuge provides a selective tilting sensation that is detectable only by the otolith organs providing conflicting information from the canal organs of the vestibular system (intra-vestibular conflict). These results indicate that VSR can improve performance in sensory conflict scenarios like that experienced during spaceflight. 3. We have showed the efficacy of VSR stimulation to improved balance and locomotor control on subjects exposed to continuous, sinusoidal lateral motion of the support surface while walking on a treadmill while viewing perceptually matched linear optic flow. 4. We have developed and tested a practical methodology of finding the optimal amplitude of VSR stimulation using perceptual thresholds indicated by seated subjects using a game pad in response to applied electrical vestibular stimulation with sinusoidal signals of varying peak amplitudes. Preliminary analysis of these data indicated that the optimal amplitude of stimulation was found to be in the range of 10 to 20% of their maximum probability of detecting the signal. 5. We have developed a methodology to detect the functional vestibular cortex using a magnetic resonance imaging (MRI) compatible device and this study is ongoing to determine the effects of VSR stimulation on brain function. 6. We have shown the safety of short term continuous use of up to 4 hours of VSR stimulation and its efficacy in improving balance and locomotor function in Parkinsonian Disease patients. Thus, maximizing postural, locomotor, and perceptual performance during dynamic movements will have a significant impact on development of vestibular SR as a unique system to aid recovery of function in astronauts after long-duration spaceflight or in people with balance disorders. The data obtained in this project will aid in the design of a countermeasure system used for improving functional tasks during and after g-transitions. The VSR methodology developed in the current project is being integrated with the sensorimotor adaptability (SA) training modalities being developed by Dr. Bloomberg and his team to improve its efficacy. The operational version of this countermeasure will be available as a skin patch vestibular prosthesis during spaceflight that will further act synergistically along with the pre-and in-flight SA training and provide an integrated, multi-disciplinary countermeasure capable of fulfilling multiple requirements making it a comprehensive and cost effective countermeasure approach.

Anticipated Benefits

Research Impact: We are proposing VSR countermeasures that will improve functional performance so that crewmembers will be able to meet early mission objectives during gravitational transitions. We envision that VSR stimulation will be available as a skin patch vestibular prosthesis during spaceflight that will further act synergistically along with the pre- and in-flight SA training to improve performance of functional tasks during gravitational transitions. This countermeasure approach can be implemented with minimal or no additional cost in terms of in-flight crew time, which is a significant advantage. The overlay of this countermeasure directly with any existing pre- or in-flight training modality to improve acquisition of skills will enhance the

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Organization:

National Space Biomedical Research Institute (NSBRI)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Principal Investigator:

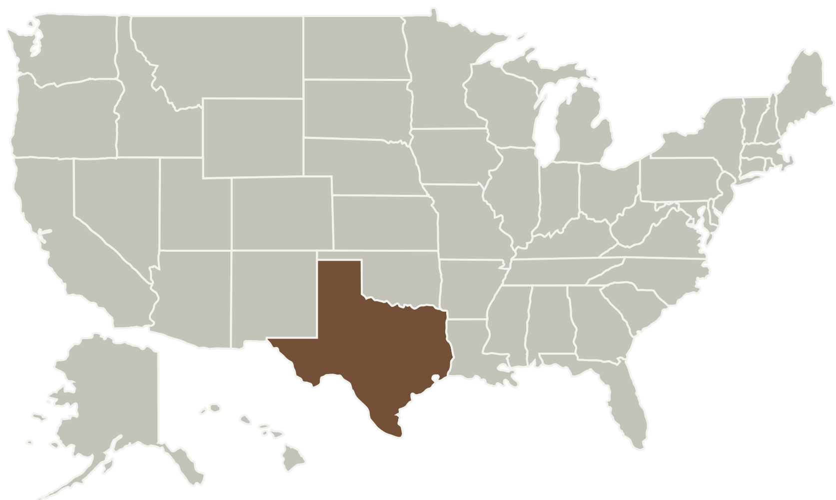
Ajitkumar P Mulavara

Co-Investigators:

Brian T Peters
Scott A Wood
Helen Cohen
Jacob J Bloomberg
Millard F Reschke

utility of the integrated, multi-disciplinary countermeasure capable for fulfilling multiple requirements making it a comprehensive and cost effective countermeasure approach. Earth-Based Applications: VSR stimulation prostheses have Earthbound application in rehabilitation of patients with balance disorders, strokes, spinal cord injury, peripheral neuropathy in the legs or a single hand that has been injured, and low vision, and for fall prevention training among seniors. This project will also enhance the efficacy of ground-based rehabilitation and training programs.

Primary U.S. Work Locations and Key Partners

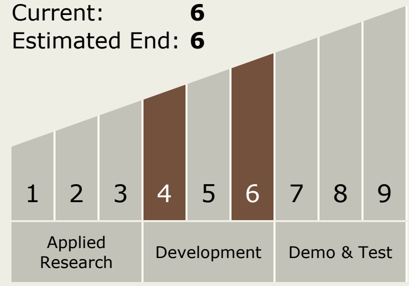


Organizations Performing Work	Role	Type	Location
National Space Biomedical Research Institute(NSBRI)	Lead Organization	Industry	Houston, Texas
KBRwyle, Inc.	Supporting Organization	Industry	Houston, Texas

Primary U.S. Work Locations
Texas

Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  └ TX06.3 Human Health and Performance
    └ TX06.3.2 Prevention and Countermeasures

Target Destinations

The Moon, Mars

Project Transitions

October 2009: Project Start

May 2014: Closed out

Closeout Summary: In years 4 and 5 this project has focussed on three tasks: 1. Developed a practical methodology to d etermine optimal stimulation levels that will enable maximizing balance and locomotor task performances during task perfor mance or training. This will enable ease of application of SR stimulation in practice. In order to improve the efficacy of impl ementation of this countermeasure a practical methodology to determine customized subject specific optimal amplitude if n oise was needed to be implemented. Towards this goal we have developed and tested a practical methodology of finding th e optimal amplitude of stimulation using perceptual thresholds indicated by seated subjects using the joystick on a game pa d in response to applied electrical vestibular stimulation with sinusoidal signals of varying amplitudes. We mapped the opti mal stimulation levels to the threshold curve obtained in previous experiments in which subjects performed both the balanc e and locomotor tasks and determined that the optimal levels of stimulation were in the range of 20-40% of threshold. 2. We examined how vestibular SR stimulation (VSR) affects measures of brain structure, functional network integrity, and ve stibular function using Diffusion Tensor Imaging (DTI), Functional Connectivity MRI (magnetic resonance imaging), and Fun ctional MRI. We have developed a methodology for using a MRI compatible tapper device which elicits vestibular evoked my ogenic potentials (VEMPs). This device enables the mapping of the functional vestibular cortex. We are conducting a further validation study comparing functional MRI data in response to both the tapper device and to auditory tone bursts to map th e functional vestibular cortex. We have collected data on 8 participants thus far, and the preliminary analyses reveal good c orrespondence in the activation patterns for the two methods. We will complete data collection on 15 participants and analy ze the data for publication. We will then move on to image vestibular responses to the low level VSR stimulation. 3. We inv estigated the safety of use and possible effects of VSR alone and combined with L-DOPA in patients with Parkinsons Disease (PD). SVS (stochastic vestibular stimulation) or sham stimulation was administered to 10 PD patients in a double-blind plac ebo controlled cross-over pilot study. Motor symptoms and balance were evaluated in a defined off-medication state and aft er a 200 mg test dose of L-DOPA, using UPDRS-III, Posturo- Locomotor- Manual (PLM) movement times (MT), static postur ography, and force plate measurements of the correcting response to a balance perturbation. Results suggest that short ter m use of SVS is safe, improves corrective postural responses, and has a small positive effect on motor symptoms in PD pati ents off treatment.

Stories

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/56752)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/56748)

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(https://techport.nasa.gov/file/56753)

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Abstracts for Journals and Proceedings *(https://techport.nasa.gov/file/56755)*

Articles in Other Journals or Periodicals *(https://techport.nasa.gov/file/56757)*

Articles in Peer-reviewed Journals *(https://techport.nasa.gov/file/56758)*

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Papers from Meeting Proceedings
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Project Website:

https://taskbook.nasaprs.com